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(54) **Peptide substrates for mammalian collagenase**

(57) Synthetic peptide substrates having high activity for the enzyme collagenase, and having amino acid sequences

R_1-Pro-Leu-Gly-Leu-Leu-Gly-R_2 and
R_1-Pro-Leu-Gly-Leu-Ala-Gly-R_2 wherein
R_1 is H or N-protecting group, and
R_2 is terminal amide, carboxyl or ester group.

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SPECIFICATION

Novel peptide substrates for mammalian collagenase

Background of the invention

This invention relates to novel peptides which have high activity as substrates for mammalian collagenase.

Collagenase is a proteolytic enzyme which acts on the protein collagen. This enzyme was early found in certain *clostridia* culture filtrates and shown to act specifically on native (undenatured) collagen at near physiological pH. See Mandl, "Collagenase and Elastases," *Advances in Enzymology 23,* p. 163, Interscience Publishers, New York, 1961. An illustrative example of a collagenase enzyme product obtained from special strains of *Clostridium histolyticum* is commercially available from Worthington Biochemical Corporation, Freehold, New Jersey.

Collagenolytic enzymes also have been obtained by tissue and cell culture from a wide range of animal species in which collagen is metabolized under both physiological and pathological conditions. Collagenase enzymes from such cell and tissue culture sources or from tissue extracts are usually obtained in exceedingly small amounts. Consequently, such enzymes are usually available only by laboratory preparation. An illustrative example of such a preparation is a purified collagenase obtained from culture media of tadpole explant as described by Nagai et al., *Biochim. Biophys. Acta 263,* 564—573 (1972).

The natural substrate collagen constitutes the connective tissue of the body and is the major type of fibrous protein in higher vertebrae, including mammals. In man, approximately one-third of the total protein content is collagen. The ability of collagenase to digest native collagen provides then enzyme with a variety of uses in tissue culture and cell studies including the isolation of tissue collagen and other types of tissue dissociation. Illustratively, achilles-tendon collagen is hydrolyzed by collagenase to peptides with an average chain length of four to five amino acids.

Collagenase also is believed to be associated with the tissue invasion process in tumor angiogenesis, in arthritic conditions such as rheumatoid arthritis, in corneal ulceration and other diseases of connective tissue. It has been suggested that tumor anglogenesis factor (TAF) induces collagenase secretion by blood vessel endothelial cells. See Moscatelli et al., *Cell 20,* 343 (1980). The ability of TAF to stimulate collagenase production in endothelial cells provides a basis for assay for TAF and anti-TAF. Accordingly, the measurement of collagenase production is a useful diagnostic tool for tissue invasion.

Conventional assays for collagenase generally are based on methodology developed by Mandl et al., *J. Clin. Invest. 32,* 1323 (1953). According to these assay procedures, collagenase is incubated for an extended period of time at 37°C with native collagen. The extent of collagen breakdown is then determined using the Moore and Stein collorimetric ninhydrin method, *J. Biol. Chem. 176,* 367 (1948). Amino acids which are liberated are expressed as micromoles per milligram of collagenase. One unit of enzyme activity equals the amount of collagenase required to solubilize one micromole of leucine equivalents.

Various synthetic substrates also have been developed heretofore as reagents for the quantitative determination of proteolytic enzymes such as thrombin, plasmin, trypsin and collagenase. These substrates generally consist of relatively short chain peptides. Under the action of the appropriate enzyme, a fragment is hydrolytically split off from the substrate with the resulting formation of a split product, the quantity of which can be measured by conventional photometric, spectrophotometric, fluorescence-photometric, and chromatographic methods. The quantity of the split product formed per time unit is a measure for the enzyme activity from which the quantity of enzyme present in a given test sample can be calculated.

The following are examples of two such synthetic collagenase substrates which are commercially available from Penninsula Labs, San Carlos, California:

DNP-Pro-Leu-Gly-Ile-Ala-Gly-Arg-OH and
DNP-Pro-Gln-Gly-Ile-Ala-Gly-Gln-D-Arg-OH,

wherein

DNP=Dinitrophenyl.

Other examples of peptide substrates for mammalian collagenases and methods of measuring collagenase activity with the substrates are described in U.S. Patents 4,138,394 and 4,176,009; Nagai et al., *Biochim. Biophys. Acta 445,* 521—524 (1976); and Masui et al., *Biochem, Med. 17,* 215—221 (1977). Further background information on mammalian collagenase also can be had by reference to the treatise "Collagenase in Normal and Pathological Connective Tissues," Woolley and Evanson, Eds., John Wiley & Son, New York, 1980.

Description of the invention

In accordance with the present invention several novel peptides have been synthesized as substrates for the enzyme collagenase. They have been found to have substantially greater activity

than the aforesaid commercially available synthetic substrates for mammalian collagenase. The novel peptides of this invention are selected from the group consisting of:

R_1-Pro-Leu-Gly-Leu-Leu-Gly-R_2 and
R_1-Pro-Leu-Gly-Leu-Ala-Gly-R_2,

wherein
R_1=H or N-protecting group, and
R_2=terminal amide, carboxyl or ester group.
The abbreviations used for the amino acids herein follow standard nomenclature in which:

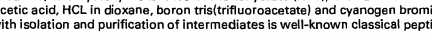
Ala=L-alanine,
Arg=L-arginine,
D-Arg=D-arginine,
Gln=L-glutamine,
Ile=L-isoleucine,
Leu=L-leucine, and
Pro=L-proline.

It, has now been found that the Gly-Leu peptide bond (amino acids 3 and 4) in the above sequences cleaves substantially more readily with mammalian collagenase than the Gly-Ile peptide bond in the corresponding position of the aforesaid commercially available peptides. It has also been found that the Gly-Leu-Leu sequence is further rate enhancing in the cleavage reaction with mammalian collagenase. Thus, the peptide of this invention containing the Gly-Leu-Leu sequence in amino acid positions 3, 4 and 5 is about 2-1/2 times as active as the corresponding peptide containing the Gly-Leu-Ala sequence in the same position. Similar enhancement is found over peptides having a Gly-Ile-Leu sequence as disclosed in applicant's copending application U.S. Ser. No. 366,520, filed April 8, 1982 (British Patent Application No. 8309496).

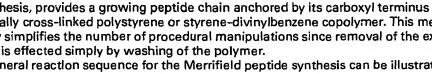
The novel peptides of this invention can be made by appropriate adaptation of conventional methods for peptide synthesis. Thus, the peptide chain can be prepared by a series of coupling reactions in which the constituent amino acids are added to the growing peptide chain in the desired sequence. The use of various N-protecting groups, e.g., the carbobenzoxy group or the t-butyloxycarbonyl group (BOC), various coupling reagents, e.g., dicyclohexylcarbodiimide, carbonyldiimidazole, or 1-hydroxy-benzotriazole monohydrate (HBT), and various cleavage reagents, e.g., trifluoracetic acid, HCL in dioxane, boron tris(trifluoroacetate) and cyanogen bromide, and reaction in solution with isolation and purification of intermediates is well-known classical peptide methodology.

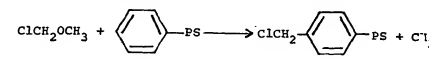
Preferably, the peptides of this invention are prepared by the well-known Merrifield solid support method. See Merrifield, *J. Amer. Chem. Soc. 85,* 2149-54 (1963) and *Science 150,* 178—85 (1965). This procedure, though using many of the same chemical reactions and blocking groups of classical peptide synthesis, provides a growing peptide chain anchored by its carboxyl terminus to a solid support, usually cross-linked polystyrene or styrene-divinylbenzene copolymer. This method conveniently simplifies the number of procedural manipulations since removal of the excess reagents at each step is effected simply by washing of the polymer.

The general reaction sequence for the Merrifield peptide synthesis can be illustrated as follows:

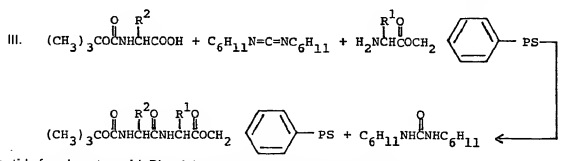
I. 

Chloromethylation Step to provide reactive group for attachment of peptide, wherein PS=Polystyrene Residue.

II. 



Esterification Step—Reaction with Triethylammonium salt of the First Protected Amino Acid (R^1) Using t-BOC Protecting Group.

III. 

Peptide forming step with Dicyclohexylcarbodiimide Coupling Agent.

This step follows cleavage of t-BOC by HCl and liberation of N-terminal amine by excess of triethylamine, thereby enabling it to react with the activated carboxyl of the next protected amino acid (R^2). A final step involves cleavage of the completed peptide from the PS resin such as by anhydrous HBr in acetic acid or trifluoroacetic acid.

Further background information on the established solid phase synthesis procedure can be had by reference to the treatise by Stewart and Young, "Solid Phase Peptide Synthesis," W. H. Freeman & Co., San Francisco, 1969, and the review chapter by Merrifield in *Advances in Enzymology 32,* pp. 221—296, F. F. Nold, Ed., Interscience Publishers, New York, 1969.

In order to determine the activity of the novel peptide substrates of the present invention, a standard collagenase enzyme solution was used to cleave the respective substrates, and the split products were then assayed by High Pressure Liquid Chromatography (HPLC). From their relative cleavage rates, the novel substrates were calculated to be from 25 to 125 times as active as the aforesaid commercially available collagenase substrates.

The following specific examples will further illustrate the invention although it should be understood that the invention is not limited to these specific examples.

Example 1

KF Method of amino acid attachment to resin:* attachment of N-t-BOC-glycine to resin

A mixture of (5.5 g, 0.031 mole) N-t-BOC-glycine, (3.6 g, 0.062 mole) potassium fluoride and (20 g, 0.0208 mole) Merrifield resin (1% crosslinked polystyrene; 200—400 mesh, 1 m.eq. chloride/gram) was suspended in 100 ml dimethylformamide (DMF) and stirred at 50° for 24 hrs. The resin was collected on a coarse fritted disk, washed twice with (DMF), 50% DMF in water, 50% ethanol in water and ethanol. The washed resin was then dried to a constant weight *in vacuo*, yielding 25.4 g of N-t-BOC-glycine on resin which gave a negative ninhydrin test and an amino acid analysis showing 0.714 m.mole/g attachment.

Other amino acids were added to the growing peptide chain by a series of coupling reactions using the desired N-t-BOC protected amino acids. The amino acids were selected such as to prepare the following peptide sequences:

A. Ac-Pro-Leu-Gly-Leu-Leu-Gly-OH, and
B. Ac-Pro-Leu-Gly-Leu-Ala-Gly-OH

wherein

Ac=acetyl.

In each case, dicyclohexylcarbodimide (DCC) was used as the coupling agent in methylene chloride solvent. After initial coupling, the α-amino protecting group was removed by trifluoroacetic acid (TFA) in methylene chloride solvent followed by triethylamine (TEA) in methylene chloride. After removal of the α-amino protecting group, the remaining protected amino acids were coupled stepwise in the aforesaid order to obtain the desired peptide sequence. Each protected amino acid was reacted in excess DCC in methylene chloride solvent. After the amino acid sequence was completed, the peptide was removed from the resin support by treatment with anhydrous HF. At each step, excess reagents were removed by washing the resin with methanol and/or methylene chloride solvents.

The sequence of reaction and washing steps carried out for each amino acid addition to the growing peptide chain for preparation of the aforesaid peptides by the solid state peptide synthesis is set forth in the following Table I.

*See Horiki et al., *Chem Letters* 165—168 (1978) for background information on this general method.

Table I
Protocol used for solid-state peptide synthesis

Wash or reactant	*Shake duration*
1. Methylene chloride	1 min.
2. 50% TFA/methylene chloride	1 min.
3. 50% TFA/methylene chloride	20 min.
4. Methylene chloride	1 min.
5. Methylene chloride	1 min.
6. Methylene chloride	1 min.
7. 10% TEA/methylene chloride	1 min.
8. Methanol	1 min.
9. 10% TEA/methylene chloride	1 min.
10. Methylene chloride	1 min.
11. Methanol	1 min.
12. Methylene chloride	1 min.
13. Amino acid/methylene chloride	1 min.
14. DCC/methylene chloride	30—90 min.
15. Methylene chloride	1 min.
16. Methanol	1 min.
17. Methylene chloride	1 min.
18. Methanol	1 min.
	66—126 min. (1—2 hrs.)

At step 14 the progress of the coupling is monitored by a ninhydrin color test.

Example 2
Synthesis of Ac-Pro-Leu-Gly-Leu-Ala-Gly-OH

To a 4 g sample of glycine on resin (0.71 μmole/mg attachment) was added (1.6 g, 8.6 mM) t-BOC-alanine in step 13 of the aforesaid protocol. This procedure was repeated with the appropriate t-BOC-protected amino acids to produce the peptide Ac-Pro-Leu-Gly-Leu-Ala-Gly-OH. A portion of the peptide was removed from the resin by anhydrous HF, extracted into methanol, and the methanol was then removed by evaporation. The one gram of crude peptide obtained was purified by the chromatographic method described in Example 5, below, m.p. 225°C.

Analysis: Calc'd. for $C_{26}H_{44}O_8N_6 \cdot H_2O$:
C, 53.3; H, 7.9; N, 14.3.
Found: C, 53.6; H, 8.1; N, 14.3.

Example 3
Synthesis of Ac-Pro-Leu-Gly-Leu-Ala-Gly-OCH_2CH_3

The peptide on resin was prepared as described in Example 2, above, and removed from the resin by heating in a suspension of triethylamine-ethanol solvent for 90 hours. The solvent was removed by evaporation and the crude peptide obtained was purified by recrystallization from ethanol-water solvent, mp >200°C.

Analysis: Calc'd for $C_{28}H_{48}N_6O_8$:
C, 56.3; H, 8.1; N, 14.0.
Found: C, 56.1; H, 8.0; N, 13.8.

Example 4
Synthesis of Ac-Pro-Leu-Gly-Leu-Leu-Gly-OCH_2CH_3

To a 3.0 g sample of glycine on resin (0.71 μmole/mg attachment) was added (1.6 g, 6.4 mM) t-BOC-leucine hydrate in step 13 of the aforesaid protocol. This procedure was repeated with the appropriate t-BOC-protected amino acids to produce the peptide Ac-Pro-Leu-Gly-Leu-Leu-Gly-OCH_2CH_3. Th peptide was removed from the resin by treatment with triethylamine-ethanol solvent, and the solvent was then remov d by evaporation; yi lding one gram of crud peptide. A 700 mg sampl was purified by recrystallization from ethanol-water solvent, yielding 250 mg of purified product, mp >200°C.

Analysis: Calc'd. for $C_{31}H_{54}O_8N_6$:
C, 58.3; N, 13.1.
Found: C, 58.3; N, 12.8.

The following example illustrates the chromatographic method used for purification of the peptide prepared in Example 2, above.

Example 5
Chromatographic method for purification of peptides

The crude peptide, after removal from resin by hydrogen fluoride, is extracted into water, neutralized to pH 6—7 and the water is then removed *in vacuo*. A portion of the residue is redissolved in a minimum of water and pipetted onto a 2 cm×15 cm C_{18} reverse-phase chromatographic column. The column is washed with three column volumes of water using a Gilson peristaltic pump. A step gradient of methanol/water, acetonitrile/water or acetonitrile/water-pH 2.5 (trifluoroacetic acid) is passed through the column to selectively elute components. The eluted fractions are monitored by HPLC and fractions rich in the desired component are pooled and lyophilized.

The following Examples 6 and 7 illustrate the chromatographic assay (by HPLC) of collagenase cleavage of the peptides prepared in the foregoing Examples 1 to 4. The collagenase used in these Examples was prepared from culture media of human skin fibroblasts according to the procedure of Stricklin et al., *Biochemistry, 16,* 1607 (1977).

Example 6
Rate of cleavage of synthetic substrates by collagenase, HPLC method

Substrate samples of 0.2—1.0 mg are weighed on a six-place balance, then dissolved in 0.05 M Tris buffer at pH 7.5 containing 0.01 M calcium chloride. The substrate concentration is adjusted to be 5.0×10^{-4} M when all ingredients are combined. The collagenase, dissolved in the same media, is activated by trypsin (10 mg/ml in 0.001 M HCl) by adding one part trypsin solution to a hundred parts collagenase solution and allowing that solution to stand at room temperature for twenty minutes. The trypsin is inactivated by adding twenty parts soybean trypsin inhibitor (5 mg/ml in 0.05 M Tris with 0.01 M $CaCl_2$).

The activated collagenase is added to the substrate solution, stirred, and a sample injected into the HPLC as a zero time measurement. The remaining sample is kept in a 35° bath and additional aliquots are removed and assayed at appropriate time intervals. The cleavage rate is determined by measuring the appearance of the peak assigned to cleavage product and/or the disappearance of the peak assigned to starting product.

Example 7

Applying the HPLC procedure of Example 6, the novel peptides of the present invention (Samples A, B and C) exhibited the following relative rates of activity in comparison to the rates of activity of the commercially available synthetic collagenase substrates (Samples D and E):

Table II

Sample no.	*Product*	*Relative rate*
A	Ac-Pro-Leu-Gly-Leu-Leu-Gly-OCH_2CH_3	250
B	Ac-Pro-Leu-Gly-Leu-Ala-Gly-OCH_2CH_3	110
C	Ac-Pro-Leu-Gly-Leu-Ala-Gly-OH	66
D	DNP-Pro-Leu-Gly-Ile-Ala-Gly-Arg-OH	10
E	DNP-Pro-Gln-Gly-Ile-Ala-Gly-Gln-D-Arg-OH	2

Various other examples will be apparent to the person skilled in the art after reading the present disclosure without departing from the spirit and scope of the invention and it is intended that all such further examples be included within the scope of the appended claims. For example, the terminal carboxyl groups in the foregoing peptides can readily be converted to amides or to other ester groups such as methyl, propyl, benzyl, p-nitrobenzyl or t-butyl ester groups; and other N-protecting groups such as t-BOC and carbobenzoxy can readily be used in place of the acetyl groups or the N-protecting group can readily be removed without departing from the basic and novel properti s of the inv ntion.

Claims

1. A peptide material having activity as a substrate for collagenase selected from the group consisting of

R_1-Pro-Leu-Gly-Leu-Leu-Gly-R_2 and
R_1-Pro-Leu-Gly-Leu-Ala-Gly-R_2,

wherein
R_1=H or N-protecting group, and
R_2=terminal amide, carboxyl or ester group.

2. The peptide of Claim 1 having the structure

Ac-Pro-Leu-Gly-Leu-Leu-Gly-OCH_2CH_3.

3. The peptide of Claim 1 having the structure

Ac-Pro-Leu-Gly-Leu-Ala-Gly-OCH_2CH_3.

4. The peptide of Claim 1 having the structure

Ac-Pro-Leu-Gly-Leu-Ala-Gly-OH.

5. A method for the determination of collagenase in a biological sample comprising reacting an aqueous solution of said sample with a peptide substrate selected from the group consisting of

R_1-Pro-Leu-Gly-Leu-Leu-Gly-R_2 and
R_1-Pro-Leu-Gly-Leu-Ala-Gly-R_2,

wherein
R_1=H or N-protecting group, and
R_2=terminal amide, carboxyl or ester group, and measuring the time of cleavage product formation.

6. The method of Claim 5 in which the peptide has the structure

Ac-Pro-Leu-Gly-Leu-Leu-Gly-OCH_2CH_3.

7. The method of Claim 5 in which the peptide has the structure

Ac-Pro-Leu-Gly-Leu-Ala-Gly-OCH_2CH_3.

8. The method of Claim 5 in which the peptide has the structure

Ac-Pro-Leu-Gly-Leu-Ala-Gly-OH.

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